Optics and Laser Technology 100 (2018) 12–20

Contents lists available at ScienceDirect

Optics and Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Full length article

Defects diagnosis in laser brazing using near-infrared signals based on empirical mode decomposition

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A R T I C L E   I N F O

Article history:
Received 6 June 2017
Received in revised form 30 August 2017
Accepted 26 September 2017

Keywords:
Laser brazing
Defects monitoring
Near-infrared signals
Empirical mode decomposition

A B S T R A C T

Real-time monitoring of laser welding plays a very important role in the modern automated production and online defects diagnosis is necessary to be implemented. In this study, the status of laser brazing was monitored in real time using an infrared photoelectric sensor. Four kinds of braze seams (including healthy weld, unfilled weld, hole weld and rough surface weld) along with corresponding near-infrared signals were obtained. Further, a new method called Empirical Mode Decomposition (EMD) was proposed to analyze the near-infrared signals. The results showed that the EMD method had a good performance in eliminating the noise on the near-infrared signals. And then, the correlation coefficient was developed for selecting the Intrinsic Mode Function (IMF) more sensitive to the weld defects. A more accurate signal was reconstructed with the selected IMF components. Simultaneously, the spectrum of selected IMF components was solved using fast Fourier transform, and the frequency characteristics were clearly revealed. The frequency energy of different frequency bands was computed to diagnose the defects. There was a significant difference in four types of weld defects. This approach has been proved to be an effective and efficient method for monitoring laser brazing defects.

1. Introduction

Laser beam welding, particularly laser brazing, is widely used for joining metal sheets in industrial applications. In particular, for the automotive sector, brazed seams are frequently in the visible part of the car body and therefore impose stringent requirements on surface quality [1]. In laser beam welding, when the laser beam impinges on the metal, it delivers its heat to the surface and further penetration beneath the surface relies on thermal conduction. In this process, the generation of high density high temperature metallic vapor and its interaction with the laser beam (so called laser plasma) occurs and strongly affects the welded bead [2,3]. Compared to the conventional arc welding processes, the advantages of laser beam welding are high-power density and low heat input. Especially for aluminum alloys welding, the joints with acceptable properties could be produced [4]. However, the stability of laser welding was significant weaker than conventional fusion welding because keyhole which coupled laser welding easily lose its stability with the unusual venting of high pressure vapor. The quality monitoring of laser welding is essential to obtain a continuous defect-free laser welding bead.

Recently, many types of monitoring methods have being developed to improve weld quality and reduce overall costs. The laser-material interactions occurred during laser welding emit energy in a variety of forms [5]. Thus, multiple sensors can be selected for various emissions. You et al. [6] presented a good review of laser welding monitoring. There is a detailed introduction to six typical sensors (photodiode, visual, spectrometer, acoustical sensor, pyrometer, plasma charge sensor) in laser welding detection. For laser plasma, Sibillano et al. [7] developed a new real-time monitoring sensor based on the acquisition of the optical spectrum to monitor the plasma electron temperature. It was found that quantitative relationship between the electron temperature and the weld penetration could be used to develop a close-loop control system of the weld penetration. Also, the depth of weld penetration was characterized by the acquired acoustic signatures, then the relationship among the acoustic signatures, the welding parameters, and the depth of weld penetration was detected in a linear manner [8]. However, the acoustical sensor including air borne and structure borne was easily subject to the interference of work surroundings. So the image of the molten pool during the laser welding may be more credible. Liu et al. [9] made the dynamics of the molten pool visualized by a high-speed charge-coupled device (CCD) camera and used a spectrometer that captured the emission spectrum of the laser-induced plasma plume

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https://doi.org/10.1016/j.optlastec.2017.09.050
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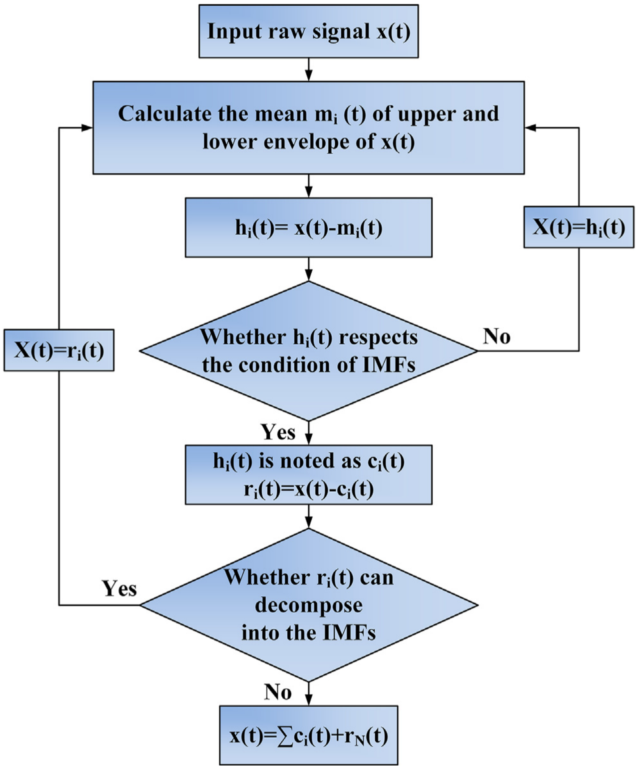

Fig. 1. Flow chart of EMD.

to study the effect of the hot-wire voltage on the stability of the welding process. However, visual inspection was not good for real-time monitoring on the industrial application because of a mass of data and complex image processing algorithm. Photodiode sensor was a typical type of industrial-scale sensors with a simple structure and low cost [6]. Gao et al. [10] chose light visible photodiode and laser reflect photodiode to monitor the status of laser welding process. When the welding status was stable, laser reflection intensity decreased to a stable value and visible light intensity fluctuated with variation of molten pool and plume status. Each sensor has own superiority for different laser welding methods and their research object. Therefore, the choice of sensors may be an important precondition to develop the monitoring system of laser welding. Likewise, the data processing and analysis was also a key to obtain good results. Bardin et al. [11] derived a spike to detect keyhole status of penetrated weld by comparing the minimum with the maximum of a set of ultraviolet and infrared signals. Meanwhile, the frequency content of the signal from the single-point sensor clearly indicated the presence of a fully opened keyhole. Fourier and autocorrelation analysis were better for finding frequencies, respectively periods, of plasma bursts [12]. Statistic feature parameters were extracted from sound and arc voltage signals in time and frequency domain, respectively. It was demonstrated that the parameters were high sensitivity to the different degree of seam penetration [13]. Kang et al. [14] pointed out the standard range from results of welding test. When the plasma intensity lay between the maximum and minimum values of the standard range, the weld quality could be judged to be acceptable. Medium-frequency component and high-frequency component of the optical signal were regarded as welding status changes. There was an obvious correlation between the high-frequency signal and welding status [15]. In addition, the Wavelet Packet Decomposition (WPD) was used to specify the major effect of photodiode signal low-frequency component on welding status and weld defect detection [16]. However, the photodiode signals were non-stationary and noisy. Recently, the Empirical Mode Decomposition (EMD) was proposed to analyze photodiode signals, which had been proved to have better performance in eliminating the influence of pulse current on the ratio signal than wavelet packet transform, it was efficient to estimate the different types of porosity defects [17]. Also, the EMD method could isolate and quantify a particular fault frequency component [18]. Meanwhile the energy-based damage indices were established with the EMD method, and there was encouraging evidence to detect the damage [19]. The application of EMD in gearbox fault diagnosis revealed satisfactory diagnostic performance [20]. However, only few researchers focused on the laser brazing defects diagnosis with near infrared signals, and chose the EMD method to analyze the inner change rules of monitoring signals. The relationships between the laser brazing defects and change rules of monitoring signals should be established for further research and application.

In this work, the status of laser brazing was monitored using infrared sensor. Simultaneously, four types of braze seams and

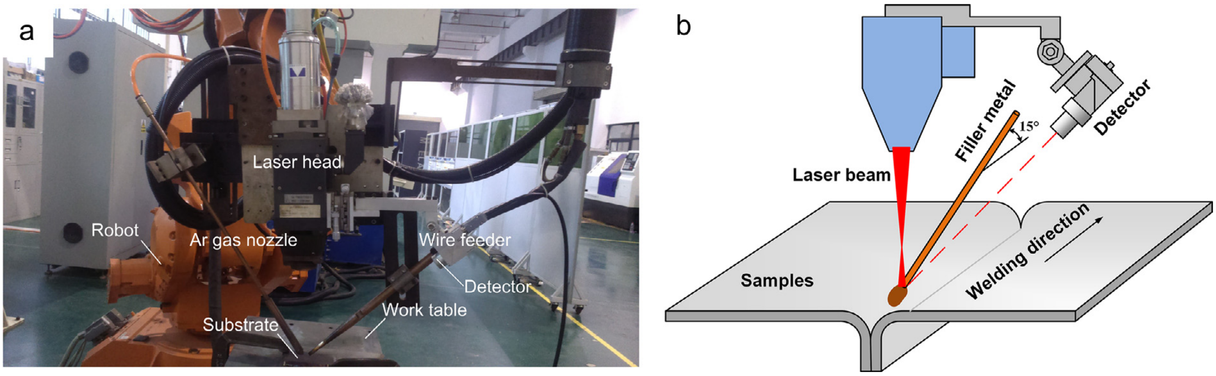

Fig. 2. Illustration of laser brazing monitoring system: (a) experimental photo and (b) schematic diagram.

Table 1
Chemical compositions of DC54D+ZF (wt.%).

Materials	C	Mn	P	S	Al	Ti	Fe
DC54D+ZF	≤0.01	0.3	0.025	0.02	0.015	0.1	Bal.